

METASOMATIC PROCESSES IN A CASSITERITE
VEIN FROM NEW ENGLAND.

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(Plates xviii.-xx.)

The chief workers on the origin and occurrence of tin in New England are Professor David, B.A., F.R.S., and Mr. E. C. Andrews, B.A. The former worked chiefly in the Emmaville District, and made the relations of the Tertiary basalts to the deep leads his main investigation.* Since Professor David's work was published, mining enterprise has caused more attention to be paid to lode-tin mining. Mr. Andrews, as a later worker, has consequently paid somewhat more attention to this phase of the subject. In his papers on the geology of New England† he has dealt at some length with the igneous formations. The granites, which occupy the largest portion of New England, he has grouped into three classes—(1) The "blue granite." (2) The "sphene-bearing granite." (3) And the "acid granite." Of these it is the "acid granite" with which the cassiterite veins of New England appear to be associated.

Mr. Andrews considers that these veins are the result of intruding solutions, of a very acid nature, into the acid granite. From his observations on the minerals developed in these veins, and their resemblances to foreign occurrences, he has expressed his opinion that the processes involved are chiefly of a metasomatic nature.

* Geology of the Vegetable Creek Tin-mining Field. Mem. Geol Survey N. S. Wales. Geology No.1(1887).

† "The Geology of the New England Plateau, with special reference to the Granites of Northern New England." Rec. Geol. Survey N. S. Wales, Vol. viii., pp.108 and 196(1905-07).

With a view to investigating in detail the processes, as compared with the criteria for metasomatism laid down by Lindgren,‡ the following work was undertaken. In June of this year, accompanied by my brother, Mr. M. Cotton, I visited the southern portion of the New England tin-bearing area, and made some observations at Tingha, Howell, Newstead, Gilgai and Elsmore. About a fortnight was spent in field-work, at a spot 6 miles to the south-west of Inverell. Here a number of cassiterite veins were examined.

Among these were the lodes of the Leviathan and Hill Cliff Tin Mines. At the former mine, the lode consists of a number of somewhat irregularly disposed veins, having a general north and south direction. To the west of this lode are a number of smaller veins, having the same general direction. One of these was selected for the purposes of analysis and microscopic investigation. This vein was one of the smaller ones, being about 10 to 11 inches wide where the sample was selected. Towards the northern end there seemed to be, as far as could be determined by hand-specimens, a progressive increase in molybdenite. Towards the southern end the vein became much more irregular, and exhibited a progressive increase in cassiterite. The molybdenite occurs in small flakes up to 2 mm. in diameter, and the cassiterite in grains and crystals of similar dimensions.

The vein at the north end is fairly regular in width, but widens greatly at the south end, where it becomes some 3-4 feet in width, with no well defined walls. A few crosscuts have been made at this end, but the cassiterite-content is too low for economic working under existing conditions. Where the lode is best defined a marked differentiation was observed.

The central portion of the vein is a band of almost pure quartz (see Analysis A, p. 225), varying from 1-3 inches in width. On either side of this band the vein-material gradually merges into the normal granite constituting the country-rock. Where this band attains a maximum thickness, large, well developed crystals of quartz, from 1-2 inches in length, are developed. These crystals

‡ "Metasomatic Processes in Fissure-Veins." Trans. American Inst. Mining Engineers, Vol. xxiv., 1900.

project into cavities. The sample selected for investigation represents a complete transverse section of the vein, showing the change into granite on each side. This sample was cut in halves by a transverse vertical cut. One half is shown in Plate xviii.

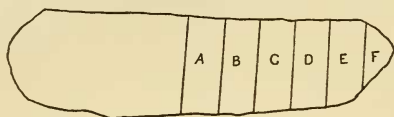


Fig. 1.—Diagrammatic section illustrating how the vein was cut. The sections A, B, C, D and E were each one inch in width. Section F was smaller, and only a small slide was obtained from it.

Text-fig. 1 illustrates how further subdivision was made on the remaining half. The six pieces lettered A, B, C, D, E, and F were formed by cuts, one inch apart. From each of the sections so formed, two slabs were cut. One of these served for making a large section for examination under the microscope; the other, which weighed about 20 grammes or more, was used as a sample for analysis. The slides, which were of large size (about 2×1 inches), when examined microscopically, supplied most abundantly all the chief phenomena laid down by Lindgren as evidences of metasomatic replacement. Slide A is from the centre of the vein. Slide G is of the normal granite. The other slides are intermediate and in alphabetical order. A description of the slides is as follows.

Slide A.—This section is almost entirely composed of quartz. A little secondary hæmatite is present, filling the fractures in the quartz. Biotite is present in very small amount, and almost invariably shows replacement by a non-ferruginous mica, the composition of which will be discussed later. The primary quartz occurs both as idiomorphic crystals, and as allotriomorphic grains; and contains abundant cavities, in most of which small liquid inclusions are present. These cavities are very small, and can be seen only under the high powers of the microscope. Most of these cavities are irregular in shape, but many of them are negative crystals of quartz. It is not uncommon to find small crystals included within the negative crystals, but, when this is so, the included crystals are too small to be determined. There

is a tendency for these crystal-cavities to be arranged in planes parallel to that of the vein. Several cavities and negative crystals are shown in Plate xix., fig.1. Topaz is possibly present in very small amount.

Slide B.—This is distinctly more basic than slide A. Mica is more abundant, and excellent examples of replacement of quartz by this mineral are common (see Plate xix., fig.2). Biotite occurs in small amount, almost invariably showing replacement by the non-ferruginous mica. A few crystals and grains of fluorite are present; these are of the colourless variety, and seem to be usually associated with the biotite.

Slide C.—This slide shows a still further decrease in quartz, and a corresponding increase in non-ferruginous mica. As in B, a small amount of biotite is present, showing replacement by the non-ferruginous mica. There is also a noticeable secondary alteration of biotite to hæmatite. Fluorite is more notable than in Slide B, but is present only in small amount (see Plate xix. fig.3). Irregular grains of what is probably molybdenite, occur scattered through the slide.

Slide D.—This section is much the same as C, but there is a still further decrease in quartz, and a corresponding increase in the non-ferruginous mica. Biotite is present in small quantities only; and, as before, shows replacement by the non-ferruginous mica. Fluorite is present in about the same amount as in Slide C, and is mainly associated with biotite. In one instance an idiomorphic crystal of fluorite penetrates a biotite crystal; and, along the line of junction, a development of the non-ferruginous mica occurs; this particular crystal of fluorite is coloured a characteristic violet. A small amount of felspar is present, and two idiomorphic crystals of albite show most perfectly the incipient metasomatic action of the non-ferruginous mica. One of these is represented in Plate xix. fig.4.

Slide E.—One side of this slide inclines towards the normal granite, and the other to the vein-material. There is, however, no definite junction-line between the two extremes. The non-ferruginous mica is present in large amount, possibly slightly in

excess of the quartz, which is less abundant than in Slide D. Felspar is present in appreciable amount, showing replacement by non-ferruginous mica, which seems to be the main metasomatic constituent throughout. This replacement of felspar has occurred chiefly, though not wholly, along the cleavage-planes. A little molybdenite, and some secondary hæmatite are present. Cavities are to be seen in the quartz present on the vein-side of the slide, but none are present in the quartz on the granite-side. Thus the presence or absence of cavities serves to distinguish the vein-quartz from that in the country-rock. On the side of the slide approaching the granitic texture, a relic of graphic structure was noted, which was distinct, though modified considerably by the replacement of both the quartz and felspar by mica.

Slide F corresponds with Slide G, save that some of the quartz and felspar show replacement by mica.

Slide G is of the normal granite. It is holocrystalline, the grain-size is variable, and graphic structure is present. Quartz is the most abundant constituent, after which albite and orthoclase are respectively the next most important. The quartz and orthoclase are frequently intergrown, giving rise to graphic structure. (See Plate xx., fig. 1). A little biotite is present, and also some secondary hæmatite. There is no fluorite present; nor is there any sign of the non-ferruginous mica, which is such a characteristic feature of the vein-material.

A series of four analyses was made, which though not quite complete, yet casts much light on the origin of the vein. The analyses A, C, and E are of those portions of the vein represented in text-fig. 1; and analysis G is of the normal granite beyond the sphere of metasomatic action. Analyses E₁ and G₁ are quoted from Lindgren,* the former representing the altered product of metasomatic action in a cassiterite vein from Altenberg and Zinnwald in Saxony, and the latter the normal granite from which this alteration took place. The following are the analyses, lettered to correspond with the text, and with text-fig. 1. The molecular ratios are also given.

* Metasomatic Processes in Fissure-veins.

Constituents.	Analysis A.	Molecular ratios.	Analysis C.	Molecular ratios.	Analysis E.	Molecular ratios.	Analysis G.	Molecular ratios.	Analysis E ₁	Molecular ratios.	Analysis G ₁	Molecular ratios.
SiO ₂	98.11	1.624	78.47	1.298	75.42	1.249	76.69	1.269	70.41	1.166	74.68	1.166
Al ₂ O ₃	0.75	0.007	11.50	0.113	12.98	0.127	10.89	0.107	14.86	0.146	12.73	0.146
Fe ₂ O ₃	0.43	0.003	2.64	0.017	1.66	0.010	0.76	0.005	1.42	0.009	—	0.009
FeO	—	—	1.05	0.015	0.58	0.007	0.39	0.004	5.09	0.071	3.00	0.071
MgO	—	—	0.49	0.012	0.23	0.006	0.18	0.004	0.09	0.002	0.35	0.002
CaO	—	—	trace	—	0.10	0.002	1.73	0.031	0.21	0.004	0.09	0.004
Na ₂ O	—	—	1.99	0.032	3.05	0.049	5.35	0.086	0.98	0.015	1.54	0.015
K ₂ O	—	—	1.17	0.013	1.62	0.017	2.97	0.032	3.01	0.032	4.64	0.032
H ₂ O +	0.04	0.002	0.23	0.013	0.47	0.027	0.13	0.007	—	—	—	—
H ₂ O -	0.02	0.001	1.17	0.065	1.31	0.073	0.37	0.021	—	—	1.17	0.065
TiO ₂	—	—	0.22	0.003	0.15	0.002	—	—	—	—	0.71	0.011
F	—	—	p.n.d.	—	p.n.d.	—	—	—	—	—	—	—
CuO	—	—	—	—	—	—	—	—	0.49	0.006	—	0.006
SnO ₂	—	—	0.08	—	0.22	0.001	—	—	3.10	0.163	—	0.163
* MoS ₂	—	—	0.80	0.005	1.69	0.011	—	—	—	0.003	0.50	0.006
MnO	—	—	—	—	—	—	—	—	0.49	0.003	0.09	0.003
Total	99.35	—	99.81	—	99.48	—	99.46	—	100.44	—	99.50	—

* Calculated from S. p.n.d. = present, not determined.

The chief error in the analyses, arising from impurities in the reagents (the purest obtainable were used), was that in the determination of the alkalis. A blank analysis was made for alkalis, which were found to give rise to an error of 0.31% of K_2O , and 0.13% of Na_2O . The figures given in the table of analyses represent the actual results obtained, less the above corrections for alkalis.

A series of curves has been drawn, after the method of Pirsson, to illustrate graphically the relationships of the analyses.

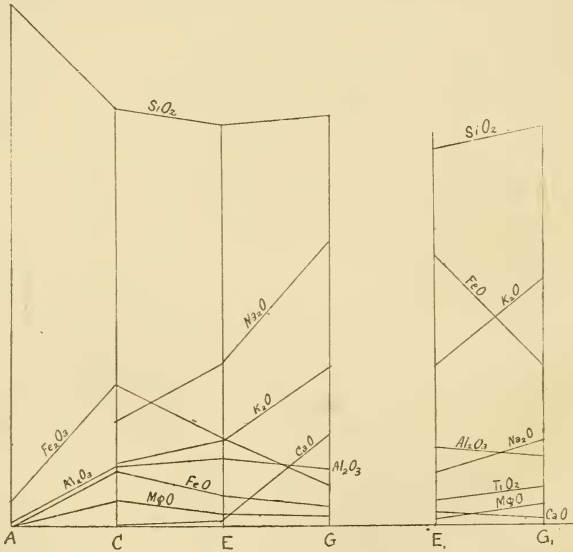


Fig 2.—Graphical representation of the tabulated analyses.

Abscissæ represent distances apart of the rocks in the field. Ordinates represent the amounts of constituents present.

N.B.— SiO_2 and Al_2O_3 plotted to one-tenth the scale of the other constituents.

From these curves it will be seen that the centre of the vein is highly siliceous, and that there is a decrease in acidity from the centre towards the contact with the country-rock. It is probable that this is, in some measure, due to differentiation in the

intruding solution. The curves indicate a minimum SiO_2 percentage in the neighbourhood of the contact of vein-material and country-rock.

From the numerous liquid inclusions present in the quartz of the vein-material, it is evident that the conditions of introduction of the vein-solutions must have been such that the pressure and temperature were above those at the critical point.*

In endeavouring to ascertain the nature of the intruding rock solution several principles seem to me to be necessary. These are:—

(1) Those constituents characteristic of the intruding solution should show a progressive decrease from the centre to the margin. Due allowance must, however, be made for magmatic differentiation within the vein itself.

(2) Those constituents characteristic of the country-rock and not of the vein, should show a decrease from the margin to the centre of the vein.

(3) Those constituents formed by the action of the intruding solution on the country-rock should show a decrease on either side of the zone of maximum metasomatic activity.

(4) Constituents which occur in approximately equal amounts in the primary vein-solution and the country-rock should appear fairly uniformly distributed throughout the whole replacement-vein.

(5) That, besides metasomatic activity *in situ*, evidence of metasomatism with transportation of substance should be sought for.

The processes active in the vein between A and C seem to have been dominated by magmatic differentiation of the intruding pneumatolytic solution. This differentiation appears to have been effective in concentrating the siliceous material chiefly at the centre, and the ferromagnesian constituents towards the margin. Between C and E the ferromagnesian constituents

* The critical temperature for water is 365°C at a pressure of 200 atmospheres.

decrease; and this would indicate that the width of the fissure, along which the solution ascended, could not have extended much beyond C. This would indicate a width of about 3 inches for the original fissure. Between C and E the curves indicate an increasing amount of alkalis and lime from the vein to the country-rock. Alumina seems to be fairly uniformly distributed between C and G, being somewhat more abundant towards C. This would indicate that the ferromagnesian product of the differentiation of the vein-material contained more alumina than the country-rock.

From the foregoing it would appear that the primary constituents of the intruding solution were SiO_2 , FeO , F , SnO_2 , MoS_2 , Fe_2O_3 and possibly Al_2O_3 and MgO . The other constituents of the vein, as analysed, were probably almost wholly derived from the country-rock. The chief of these are CaO , Na_2O , K_2O , and possibly TiO_2 .

A comparison of E_1 and G_1 with E and G shows that these deductions are in harmony with those made by Dr. Dalmer on Analyses E_1 and G_1 . With regard to the alteration in the country-rock G_1 caused by the metasomatic action yielding the product E_1 ; Lindgren states that "Dr. Dalmer concludes that the principal changes consisted in the addition of FeO , F , SnO_2 and possibly Al_2O_3 , while K_2O , Na_2O , and SiO_2 have been subtracted. In the absence of further knowledge of the relations of volume during the alteration, it is scarcely possible to conclude, from the comparison of these analyses alone, what the actual changes have been."

In attempting to trace the actual metasomatic changes, I was soon convinced that though, with my present data, the problem was an indeterminate one, yet the following generalisations seemed to be justified.

The resulting product of metasomatism has given rise to a non-ferruginous mica, to fluorite and possibly topaz. The nature of the mica, which is the characteristic replacing constituent, is an indeterminate problem. It depends on the amount of secondary hæmatite present; and also on the composition of the biotite,

which is itself unknown. However, it seems fairly certain that this mica was formed, in great part, by the replacement of the feldspars, so that the alkali-molecules were retained in the new product. The composition of the mica seems to be a mixture of paragonite and sericite molecules, with replacement of some of the H_2O molecules by Na_2O . Its general composition may be written $3(K, H, Na)_2O, 3Al_2O_3, 6SiO_2$. It is possible that some Li is also present, as this was not sought in the analyses. It is also more than probable that some F enters into the composition of this mica.

Criteria of Metasomatism.—If the results discussed above be judged by the criteria for metasomatism given by Lindgren, it will be seen, I think, that the evidence for such action is complete. Lindgren (*op. cit.*) states the following.

(1) "The only decisive criterion is that of metasomatic pseudomorphism involving the proof (generally to be furnished by microscope study) as to whether simultaneous dissolution and deposition have actually taken place. The most satisfactory proof is the distinct alteration of well defined crystals (or, at least, well defined grains) of the original mineral into the secondary mineral in such a way that the latter projects into the former in prisms or fibres having crystalline outlines."

(2) "Another proof is afforded by sharply defined crystals of the secondary embedded in the primary mineral, without any break between their surfaces; but in this case it must be clear that the mineral is really secondary and was not formed before the primary."

(3) "The occurrence of *nuclei* of unaltered rock is sometimes an available criterion, but it must be used with caution; and probably has given rise to misinterpretations, on account of its similarity to actual inclusions of country rock in vein-filling."

(4) "Generally . . . the replacement proceeds very irregularly, owing to the effect of little cracks and fissures."

In quoting the above, I have taken the liberty of numbering the paragraphs for reference. The alteration of quartz into the characteristic mica is a good illustration of No.1. Plate xx., fig.2, shows this. This alteration is abundant in Slides B, C, D and E.

An excellent example of No.2 is given in Plate xix., fig.4, which illustrates the albite crystal described from Slide D. Complete crystals of mica are present in the felspar without discontinuity of their surfaces.

Plate xx., fig.3, illustrates No.3. Here biotite has been replaced by the paragonite-sericite mica, and several pieces of the former are completely surrounded by the latter. Almost any random section will serve to illustrate how the replacement has taken place along cracks and fissures, thus illustrating No.4. An example of this is afforded by Plate xx., fig.4.

Mr. Emmonds has suggested the following field-structures as necessary criteria—

(1) "Absence of symmetrical banding or comb-structures in the vein-material, and of breccias of country-rock cemented by vein-material."

(2) "Great irregularity in width of the ore-bodies, which may reach very great dimensions."

(3) "General lack of definition between ore-body and wall-rock."

Though, in the microscopical examination, it was noted that the cavities in the primary vein-quartz had a tendency to arrangement in planes parallel to the fissure-plane, yet in no sense could it be said that symmetrical banding was present. Field-observations failed to detect either the slightest trace of such banding, or of breccias of country-rock included in vein-material.

The irregularity in width of the vein examined has been already mentioned. The fact that there is a progressive change from ore-body into country-rock shows that there is a lack of definition between the two. Thus the chain of evidence for metasomatism seems complete.

Summary—A sample constituting a complete transverse section of a cassiterite vein from near Inverell in New England was selected for examination. The object was to investigate the processes involved in the formation of such veins, these processes having been generally described as being of a metasomatic

nature, by Mr. E. C. Andrews, B.A., in his work on "The Geology of the New England Plateau."

A series of slides, covering the entire distance from the centre of the vein to the country-rock, was examined, and a series of four analyses, three of the vein-material and one of the country-rock, were undertaken. The former, when judged by the criteria for metasomatism suggested by Lindgren, were found to give abundant evidence of such action. The analyses were used to deduce the processes which were dominant in the formation of the vein. A diagram of the analyses, after the method of Pirsson, was constructed to show the relations graphically. Two analyses used by Dr. Dalmer in a similar, but less detailed examination, were included for comparison. From the variation in the analyses it is probable that the fissure, along which the solutions rose, was not more than 3 inches in width, and that the total width of about 10 inches is due to metasomatic replacement of the country-rock. The constituents of the solution, which was probably under pneumatolytic conditions, were found to be chiefly SiO_2 , FeO , MgO , SnO_2 , MoS_2 , and Al_2O_3 . These acted on the country-rock, which is a granite; and, by molecular replacement, formed a vein-product containing the above-mentioned constituents, plus CaO , Na_2O , K_2O , and TiO_2 , probably derived from the granite. The characteristic metasomatic product is a paragonite-sericite mica, with Na_2O replacing some of the H_2O molecules. The exact composition of this mica is indeterminate, and it quite probably contains fluorine. A second metasomatic product is fluorite, probably formed by the action of the fluorine-bearing solution on lime-feldspars in the country-rock.

Finally, a comparison of the analyses and deductions with those made by Dr. Dalmer in his work on the tin-deposits of Altenberg and Zinnwald in Saxony, gave quite harmonious results.

In conclusion, I would like to express here my thanks to Dr. W. G. Woolnough, F.G.S., Acting Professor of Geology at the University of Sydney, for the kindly interest he has taken in this work, for his ever-ready help, and for the unstinted

manner in which he has placed every facility at my disposal in the carrying out of this investigation.

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EXPLANATION OF PLATES XVIII.-XX.

Plate xviii.

Section across the fissure-vein, showing normal granite on each side, and vein-material between.

Plate xix.

- Fig. 1.—Section showing cavities, and negative crystals in vein-filling; ($\times 70$).
Fig. 2.—Quartz showing replacement by non-ferruginous mica. Crossed nicols; ($\times 20$).
Fig. 3.—Showing fluorite in centre, and biotite replaced by non-ferruginous mica; ($\times 20$).
Fig. 4.—Albite crystal, showing replacement by non-ferruginous mica; ($\times 20$).

Plate xx.

- Fig. 1.—The normal granite, with graphic structure. Crossed nicols; ($\times 20$)
Fig. 2.—Replacement of quartz by non-ferruginous mica; ($\times 20$).
Fig. 3.—Biotite, with replacement by non-ferruginous mica; ($\times 20$).
Fig. 4.—Quartz, showing replacement by non-ferruginous mica along cracks; ($\times 20$).